

ELECTROMAGNETIC PUMP

Cross Reference To Related Applications

[0001] This application claims the benefit of U.S. Provisional Application No. 60/464,317 filed April 21, 2003, hereby incorporated herein by reference.

5 Field of the Invention

[0002] The present invention relates to electromagnetic pumps that move an electrically conductive fluid by interaction with magnetic fields.

Background of the Invention

[0003] Electromagnetic pumps can be used to pump electrically conductive fluids, such as an 10 electrically conductive molten metal composition. An advantage of an electromagnetic pump is that the fluid can be magnetically induced to move through a tube or conduit without the use of mechanical pump components inside of the conduit.

[0004] Known electromagnetic pumps are either submersed in, or integrally attached to, the 15 source of the electrically conductive fluid, such as a metal melting and/or melt holding furnace. These pump installations are difficult to service and maintain. Therefore there is the need for an efficient and easily maintainable electromagnetic pump that is not integrally attached to the source of the electrically conductive fluid.

Brief Summary of the Invention

[0005] In one aspect, the invention is apparatus for and method of pumping an electrically 20 conductive material in a pump having a supply section or volume, and a magnetic force pumping section or volume. In one example of the invention the directional flow of the material through the supply section is opposite to the directional flow of the material through the magnetic force pumping section. Multiple coils surround the supply and magnetic force pumping sections. Current flowing through the multiple coils creates magnetic fields that magnetically couple with a 25 magnetic material disposed between the supply and magnetic force pumping sections so that the fields penetrate the electrically conductive material in the magnetic force pumping section substantially perpendicular to the desired flow direction. This field orientation maximizes the magnitudes of the magnetic forces applied to the electrically conductive material in the magnetic force pumping section.

[0006] These and other aspects of the invention are set forth in the specification.

Brief Description of the Drawings

[0007] The figures, in conjunction with the specification and claims, illustrate one or more non-limiting modes of practicing the invention. The invention is not limited to the illustrated
5 layout and content of the drawings.

[0008] FIG. 1 is a side perspective view of one example of an electromagnetic pump of the present invention.

[0009] FIG. 2 is a side elevational view of one example of an electromagnetic pump of the present invention.

10 [0010] FIG. 3(a) is a side sectional view through line A – A in FIG. 2 of one example of an electromagnetic pump of the present invention.

[0011] FIG. 3(b) is a top sectional view through line B – B in FIG. 2 of one example of an electromagnetic pump of the present invention.

15 [0012] FIG. 3(c) is a partial sectional view of the interface region for inner, mid and outer tubes, and magnetic material, used in one example of an electromagnetic pump of the present invention.

[0013] FIG. 4(a) is a simplified schematic diagram of a power supply and power distribution to induction coils used with an electromagnetic pump of the present invention.

20 [0014] FIG. 4(b) is a vector diagram illustrating one example of phase distribution of the output of a power supply to the induction coils used with an electromagnetic pump of the present invention.

[0015] FIG. 5 is a side sectional view of another example of an electromagnetic pump of the present invention.

Detailed Description of the Invention

[0016] Referring now to the drawings, wherein like numerals indicate like elements, there is
25 shown in the figures one example of electromagnetic pump 10 of the present invention for pumping an electrically conductive material, such as an electrically conductive molten metal. In FIG. 1, twelve induction coils (12a through 12l) as further described below, are surrounded by a

plurality of vertical magnetic shunts 14 held in place by shunt supports 16, which are attached to base 18 at one end, and to yoke 20 at the opposing end. The base and yoke may optionally be formed from a magnetic material to provide bottom and top magnetic field containment. Other shunt and outer support arrangements as known in the art may be used in lieu of the shunt and support arrangements shown in **FIG. 1**. Pump inlet 24 and pump outlet 22 in this non-limiting example of the invention, are cylindrically formed from a suitable heat-resistant material.

[0017] Referring now to **FIG. 3(a)**, which is a side sectional of electromagnetic pump 10 shown in **FIG. 2**, optional thermal insulator 26 separates the induction coils from the interior of the pump and provides a means for molten metal (melt) heat retention for melt in the pump. In this 10 non-limiting example of the invention, the thermal insulator is substantially shaped as an open cylinder bounded by base 18 and yoke 20. Outer tube 28 in this non-limiting example of the invention, is a substantially cylindrically-shaped tube that has a closed rounded bottom and an opened top with a protruding lip around the opening. The outer tube's lip sits on top of yoke 20. First closing means 30 seats over yoke 20 and the protruding lip of the outer tube. Second 15 closing means 32 seats over first closing means 30. Outlet 22 is disposed between the first and second closing means. Mid tube 34 in this non-limiting example of the invention is a substantially cylindrically-shaped tube that is opened at both ends with the upper end having a protruding lip around the opening. The mid tube's lip is seated in a recess in second closing means 32. The first and second closing means are arranged to form an outlet annular volume 42 20 that connects the interior passage of outlet 22 to riser annular volume 44 that is disposed between the outer wall of mid tube 34 and the inner wall of outer tube 28. Third closing means 36 seats over second closing means 32. Inner tube 40 in this non-limiting example of the invention is a substantially cylindrically-spaced tube that has an open bottom and a closed top. As best seen in **FIG. 3(c)** the perimeter of the inner tube's open bottom forms a fluid tight seal with the perimeter 25 of the mid tube's open bottom. Magnetic material 46 is disposed in a volume between the outer wall of inner tube 40 and the inner wall of mid tube 34 as further described below. Fourth closing means 38 seats over third closing means 36 and the closed top of inner tube 40. Inlet 24 is disposed between the third and fourth closing means and its interior passage is connected to the interior passage of inner tube 40. **FIG. 3(b)** is a sectional view that illustrates the spatial 30 relationship of components in a horizontal plane.

[0018] The above non-limiting examples of the invention provide a convenient means for assembly or disassembly of pump 10. Removal of fourth closing means 38 allows inlet 24 and inner tube 40 to be raised out of the pump. Further removal of third closing means 36 allows

magnetic material **46** and mid tube **34** to be raised out of the pump. Further removal of second closing means **32** allows removal of outlet **22**. Further removal of first closing means **30** allows removal of outer tube **28**.

[0019] The above examples of the invention provide a convenient means for changing the angular orientation between inlet **24** with outlet **22**. In a particular installation, supply and outlet conduit (not shown in the drawings) that are to be connected to inlet **24** and outlet **22** respectively, may not be oriented to accept the 180 degrees angular orientation (looking down on the top of the pump) between the inlet and outlet for pump **10** as shown in **FIG. 1**. First closing means **30** and second closing means **32** may be rotated and secured into a position different from that shown in **FIG. 1** to change the angular orientation of inlet **24** to outlet **22**, which outlet is contained by the first and second closing means. Third closing means **36** and fourth closing means **38** may be rotated and secured into a position different from that shown in **FIG. 1** to change the angular orientation of outlet **22** to inlet **24**, which inlet is contained by the third and fourth closing means.

[0020] Molten metal flows through pump **10** in the direction indicated by the arrows in **FIG. 3(a)**. The melt enters the pump through inlet **24** and flows down the interior cylindrical passage of inner tube **40**. This section of the pump is referred to as the supply section. The melt then moves by magnetic forces, as further described below, up riser annular volume **44** (the magnetic force pumping section), into outlet annular volume **42**, and finally out of the pump through outlet **22**. In other examples of the invention, outlet **22** may connect directly to riser annular volume **44** rather than being intermediately connected to it by outlet annular volume **42** formed between the inner wall of mid tube **34** and the inner annular walls of the first and second annular closing means. The outer tube, mid tube and inner tube are formed from a suitable heat resistant material such as a ceramic composition. One non-limiting type of ceramic composition that may be used to cast the outer, mid and inner tubes, as well as inlet **24** and outlet **22** is a silicon-aluminum-oxynitride composition known as sialon.

[0021] As disclosed above an applied magnetic force causes the electrically conductive melt to flow through pump **10**. There is shown in **FIG. 4(a)** one diagrammatic example of supplying power to the induction coils to cause the molten metal to flow through pump **10** by magnetic force. Power supply **48** is a three-phase output power supply with variable output frequency and output voltage. One suitable type of supply is a solid state supply with a pulse width modulated output. **FIG. 4(b)** is a vector diagram illustrating a six-cycle connection scheme from the power

supply to the coils that is used to produce magnetic forces that act on the molten metal in riser annular volume **44** to force the melt up the riser annual volume and through outlet **22**, and thus pulling molten metal through pump **10** from a suitable source of molten metal that can be connected to inlet **24**. As illustrated in the diagram and vector diagram, the six-cycle scheme is
5 created by sequentially connecting each of the three phases with alternating positive and negative phase orientation. That is phase +AB is followed by phase -BC, which is followed by phase +CA, which is followed by phase -AB, which is followed by phase +BC, which is followed by phase -CA. The six-cycle connection scheme for induction coils **12a** through **12f** repeats for induction coils **12g** through **12l**. The choice of a six-cycle connection scheme is not limiting, but
10 a six-cycle scheme (with 30 electrical degrees phase angle between voltages in adjacent coils) provides a more uniform flow rate than, for example, a three-cycle scheme (with 60 electrical degrees phase angle between voltages in adjacent coils). Since the magnitude of the output voltage of power supply **48** is directly proportional to the magnitude of the magnetic force applied to the molten metal, varying the output voltage of the power supply will vary the
15 magnetic lifting force and flow rate of a molten metal through the pump.

[0022] The magnetic forces generated in riser annular volume **44** are substantially vertical in the upwards direction since the magnetic field generated around each of the coils substantially forms a magnetic circuit with magnetic material **46** and the field path through the molten metal in the riser annular volume is substantially horizontally-oriented. If a hot molten metal is pumped by
20 electromagnetic pump **10**, magnetic material **46** must have a Curie temperature (point at which the magnetic material loses its magnetic properties) greater than the temperature of the molten metal flowing through the pump. For these applications a high Curie temperature magnetic material must be used. For example, molten aluminum typically may flow through the pump at a temperature of ranging from 680°C to 800°C. For this application the magnetic material must
25 have a Curie temperature of at least 850°C which is the maximum temperature of the aluminum melt plus design margin. One suitable type of high Curie temperature magnetic material **46** for this application is a class of iron-cobalt alloys known as permendur.

[0023] It is preferable, but not required, that each induction coil be formed as a thin-wire, multiple-turn (typically 500 or more turns) coil commonly referred to as a bobbin magnetic coil
30 since it is formed by winding thin wire around a bobbin that is removed after winding. Since the magnitude of magnetic force created by a magnetic field is directly proportional to both current flow through the coil and the number of turns in the coil, using a coil with a large number of turns

keeps the required output current from power supply 48 at a low level for a given magnitude of magnetic force.

[0024] If the source of molten metal to the pump is located below the horizontal level of inlet 24, pump 10 will need to be initially primed by filling the interior passage of inner tube 40 with melt. One method of accomplishing this is by attaching a vacuum pump to outlet 22 and drawing a vacuum on the melt flow passages within pump 10 to suction melt from a supply of molten metal connected to inlet 24. In other examples of the invention, the top of inner tube 40

5 may be open and penetrate through fourth closing means 38 in, for example, a funnel-shaped opening into which molten metal can be poured to prime the pump by filling the inner tube.

10 [0025] When pump 10 is not in use, stationary molten metal in the pump may cool and "freeze" within the pump's internal flow passages. To prevent this from happening, a cyclical emptying and filling of riser annular volume 46 with molten metal may be electromagnetically

accomplished. Reversing the direction of all phase vectors in FIG. 4(b) will create a magnetic force on molten metal in riser annular volume 46 that will force it down and push molten metal

15 back though inlet 24 to the source of molten metal connected to the inlet. Subsequently reversing all phase vectors back to the directions shown in FIG. 4(b) will create a magnetic force that will cause molten metal to rise up in the riser annular volume. This jogging motion of molten metal will prevent freezing of molten metal in the pump when it is not in use. In other examples of the invention, if a three phase power supply is used, cyclically reversing two of the phases with, for

20 example, solid state switches, can also be used to accomplish the electromagnetic jogging motion of melt in the pump. In other examples of the invention, a heating medium, such as a circulating hot gas or liquid, or an electric heating element, may be provided in the volume between thermal insulator 26 and the outer wall of outer tube 28.

[0026] FIG. 5 illustrates another example of an electromagnetic pump of the present example.

25 In this example, inlet 24a is at the bottom of the pump and molten metal is electromagnetically pumped directly up riser annular volume 46 as generally described in previous examples of the invention. In this particular example since molten metal does not flow through the inner tube, the inner tube may be a totally enclosed tube or other inner structural element that serves as a means for containing magnetic material 46 between the inner structural element and mid tube 34.

30 [0027] Other types of power supply and distribution arrangements are contemplated within the scope of the invention. For example, multiple single phase power supplies may be used; each coil may be powered by an individual power supply; or separate power supplies may power

individual groups of coils. Further although in the above examples of the invention the inner, mid and outer tubes have their longitudinal axes vertically oriented, the longitudinal axes of the tubes may be otherwise oriented without deviating from the scope of the invention.

[0028] The examples of the invention include reference to specific electrical components. One skilled in the art may practice the invention by substituting components that are not necessarily of the same type but will create the desired conditions or accomplish the desired results of the invention. For example, single components may be substituted for multiple components or vice versa.

[0029] The foregoing examples do not limit the scope of the disclosed invention. The scope of the disclosed invention is further set forth in the appended claims.